IP Measurements at PEP-II with BaBar

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Super-B III Workshop

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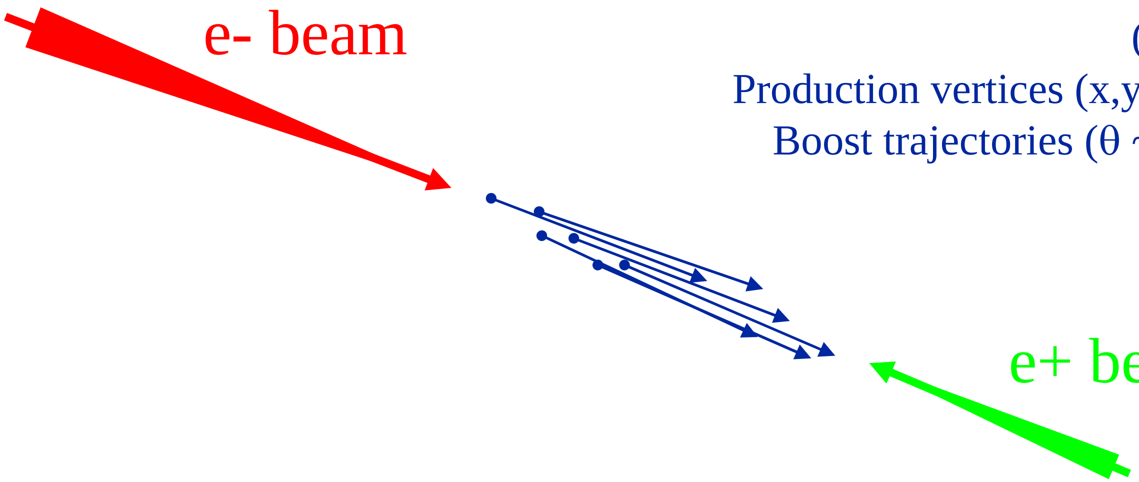
IP Characterization

- BaBar's tracking resolution and prime venue allow measurement of important parameters at the IP



(resolution)
Production vertices (x,y,z ~ 30μm)
Boost trajectories (θ ~ 0.6 mrad)

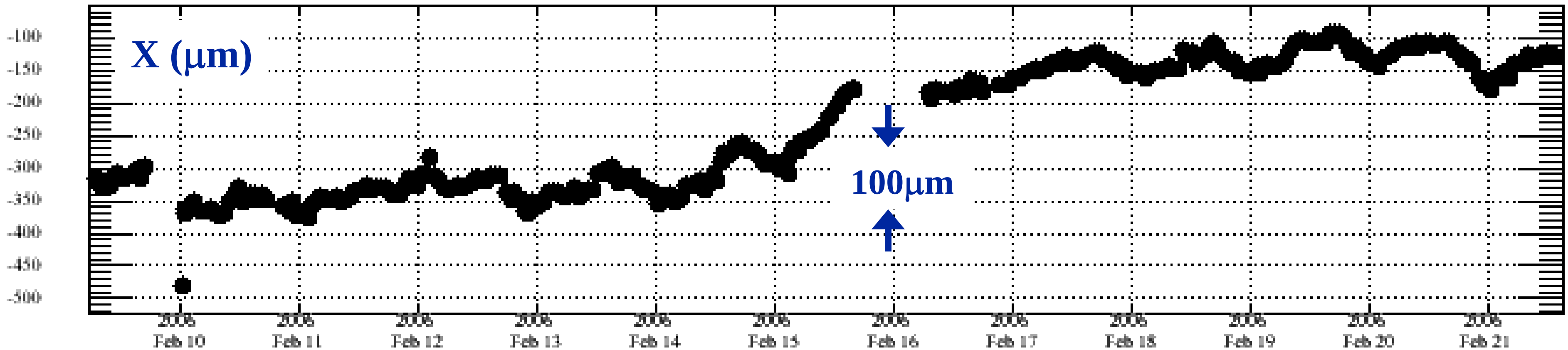
- Use $e^+e^- \to \mu^+\mu^-, e^+e^-(\gamma)$

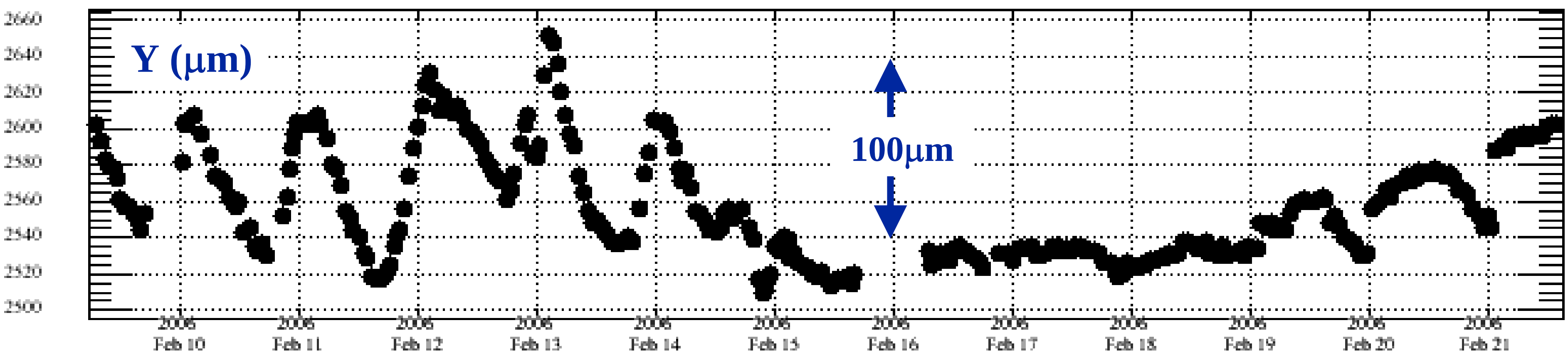
to measure production vertices and boost vector angles

Vertexing

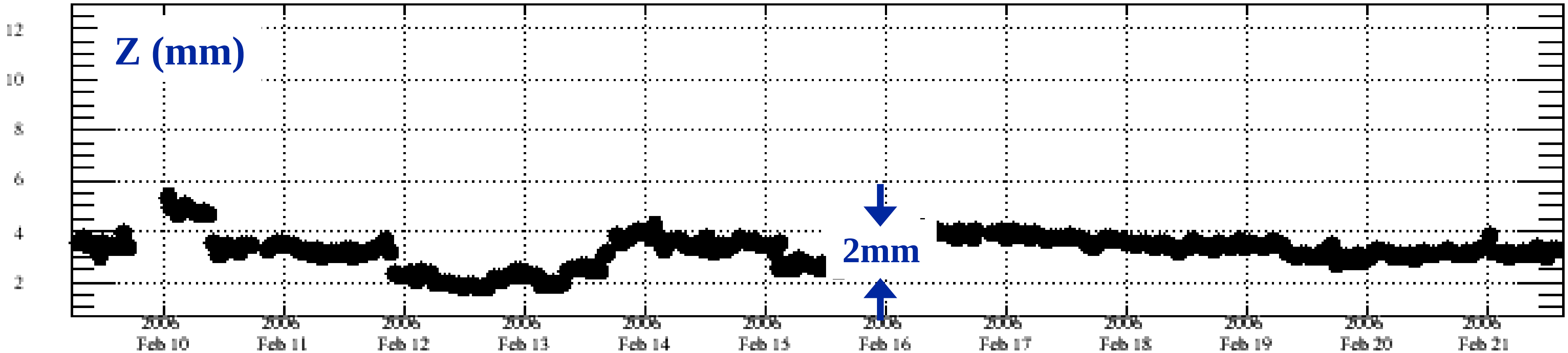
$$e^+e^- \to \mu^+\mu^-, e^+e^-(\gamma)$$

- <X>, <Y> provide steering information

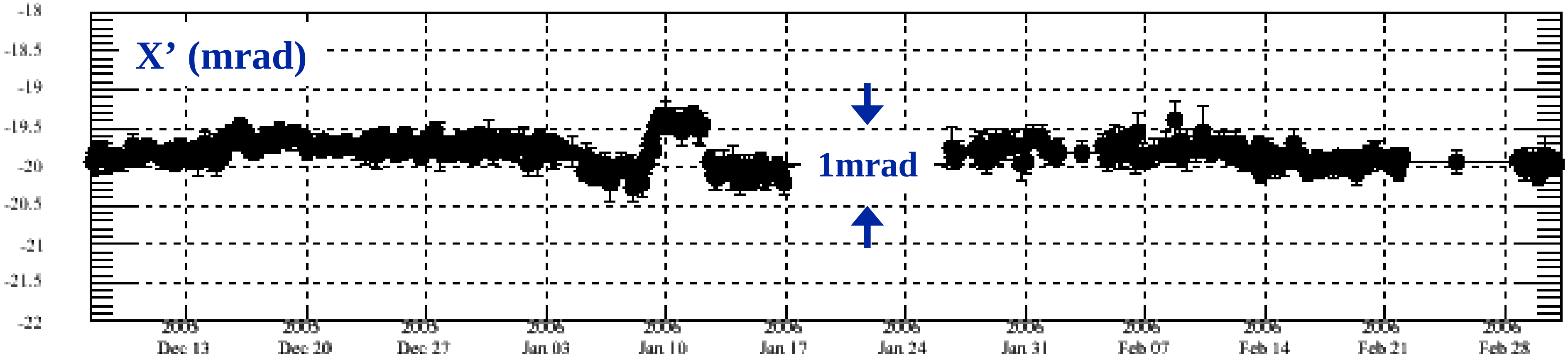


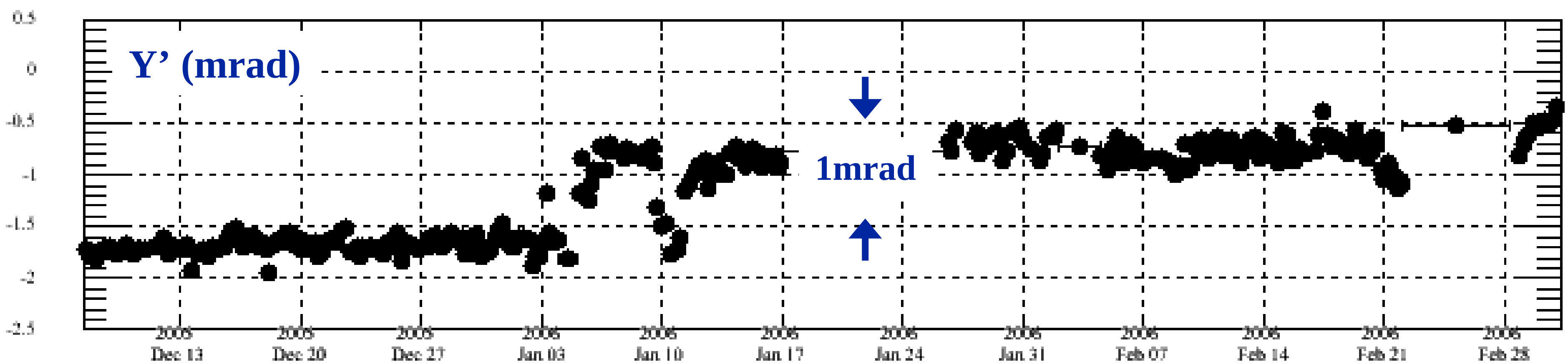


- <Z> measures relative RF phase

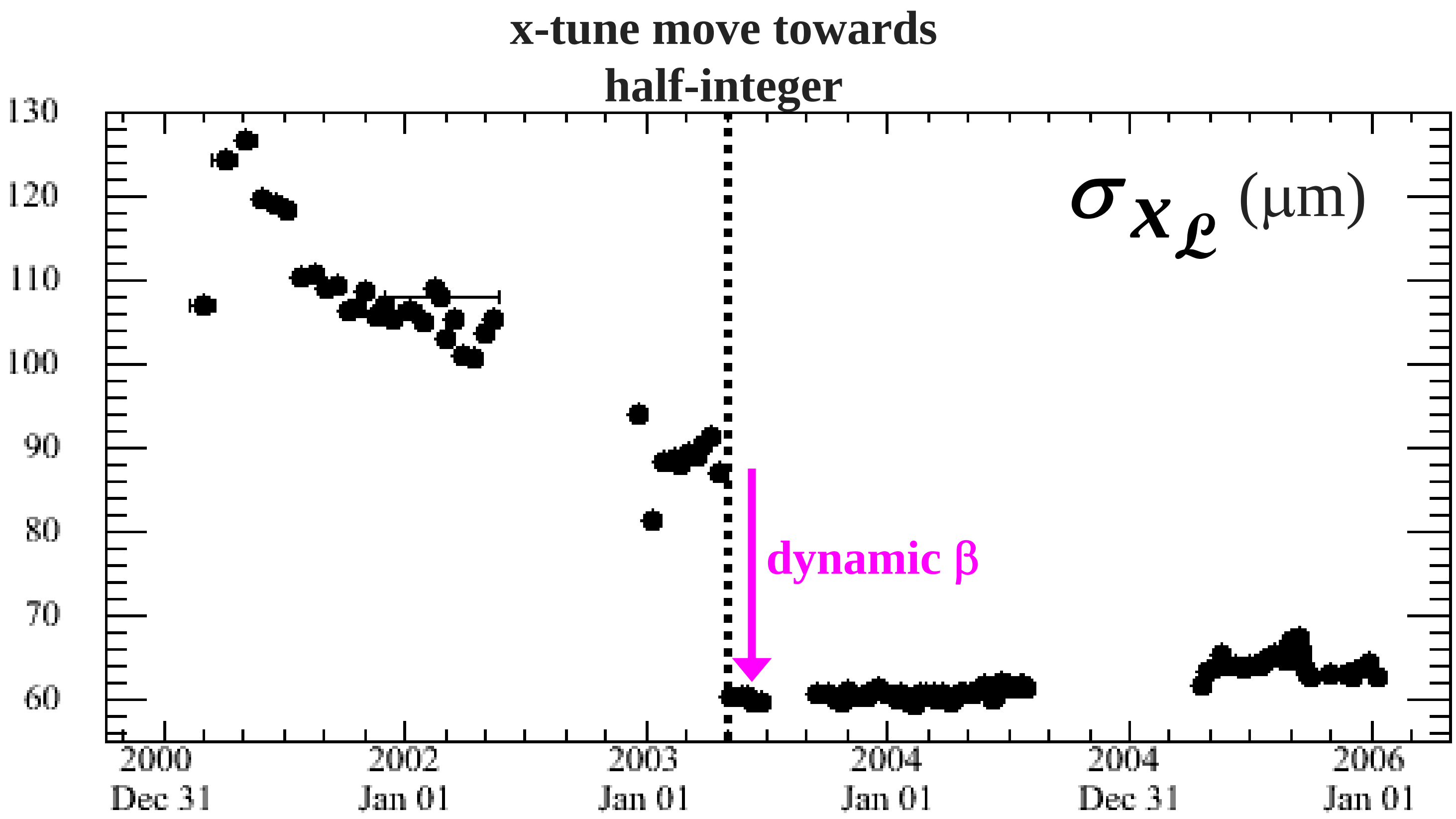


- d<X>/dz, d<Y>/dz is one measure of the collision axis





- **X-size of luminous region determined by emittances and IP-beta functions**



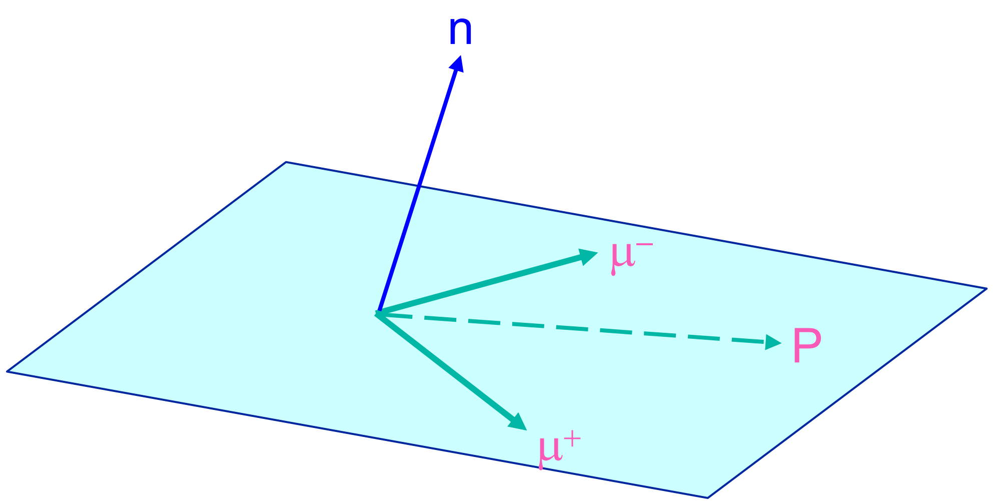
Boost Trajectory

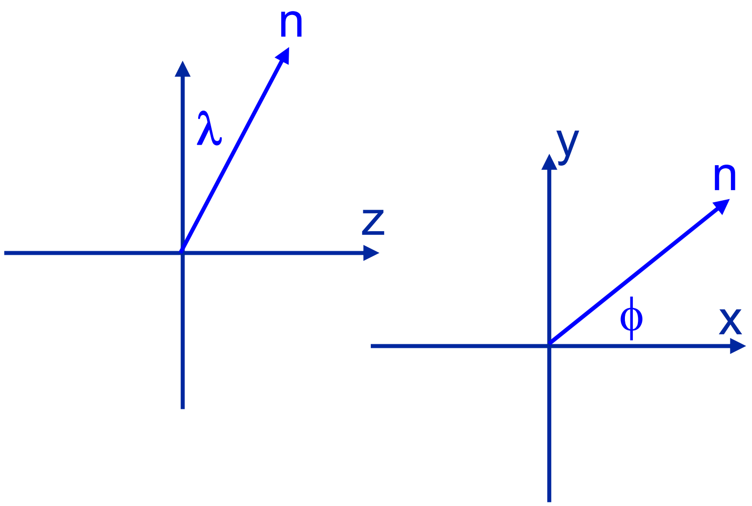
$$e^+e^- \to \mu^+\mu^-$$

- **Technique**

μ momenta poorly measured
μ trajectories well measured

reconstruct $\mu\mu$ decay plane normal n

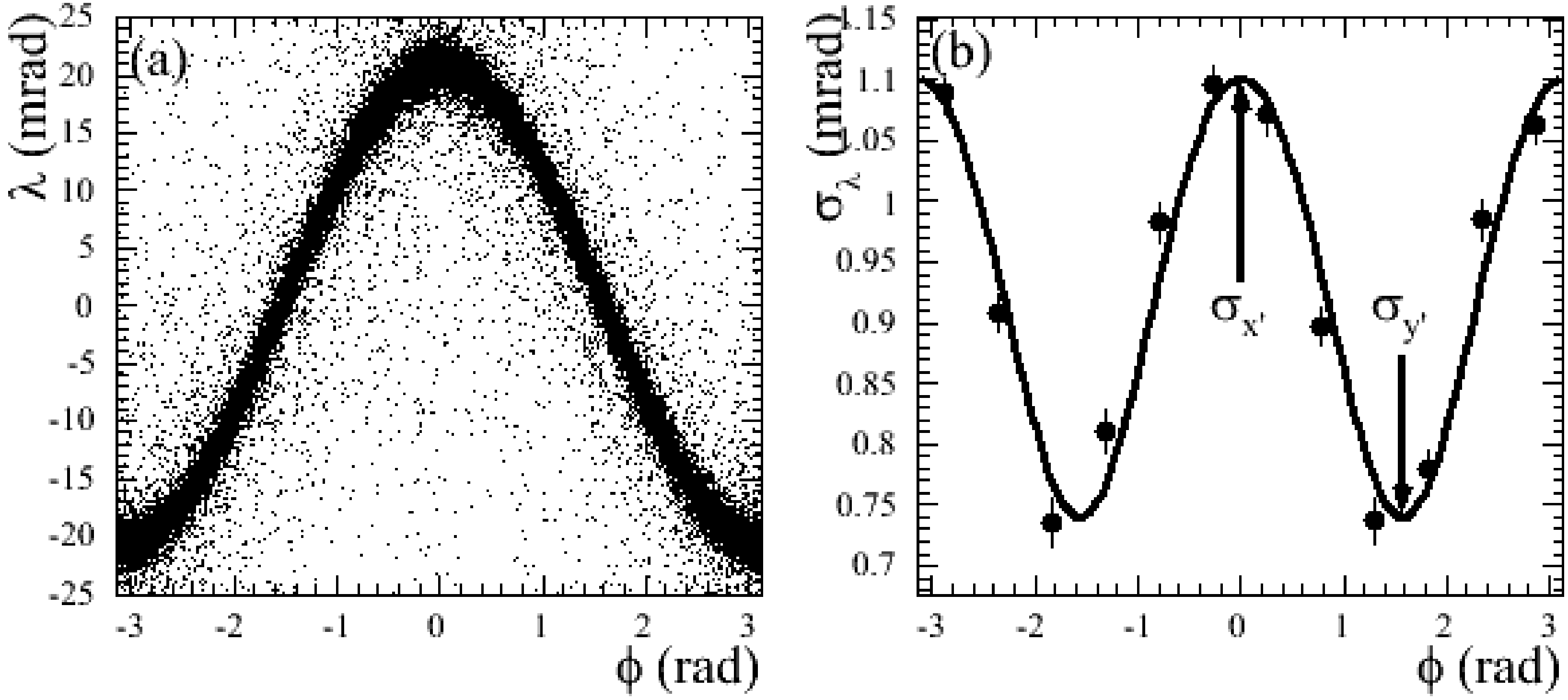




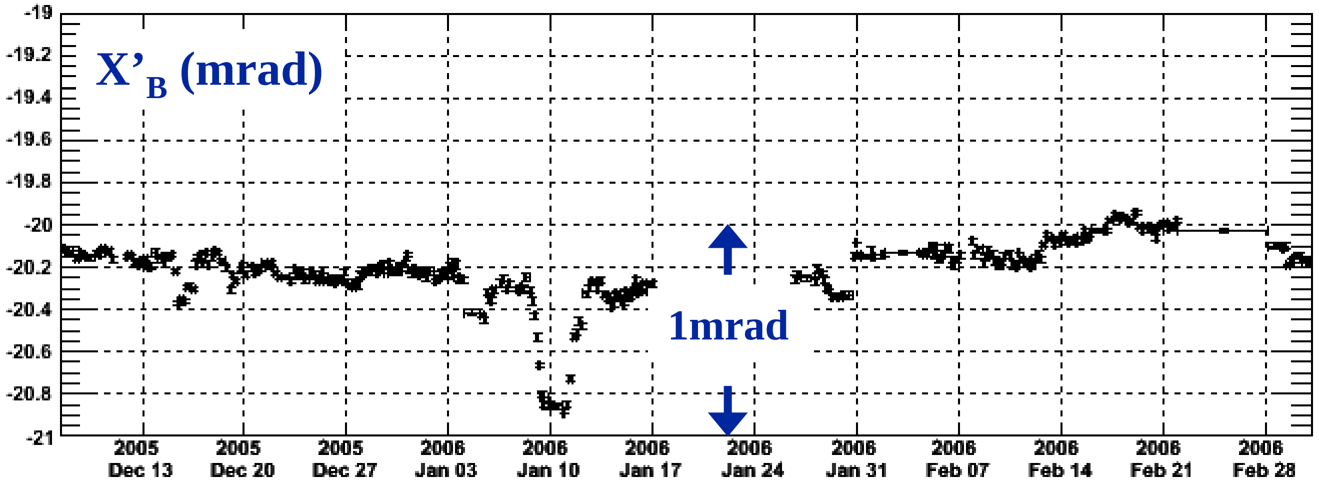
Boost Trajectory

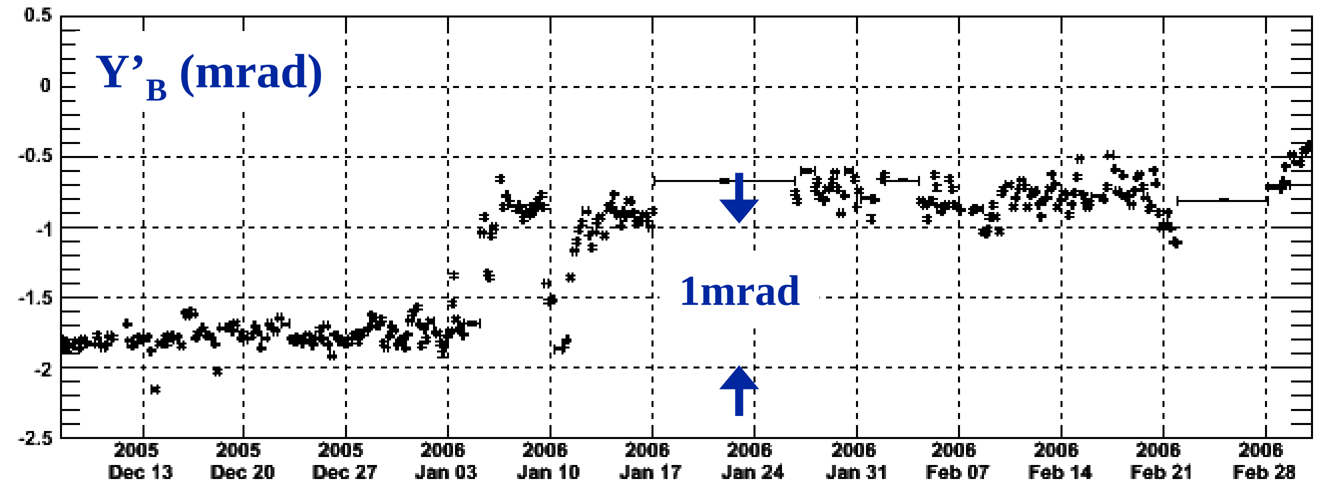
$$\tan\lambda = -\,x'_B\cos\phi - y'_B\sin\phi \approx \lambda$$

$$x'(\text{or } y')_B = \frac{E_H\, x'_H - E_L\, x'_L}{E_H - E_L}$$



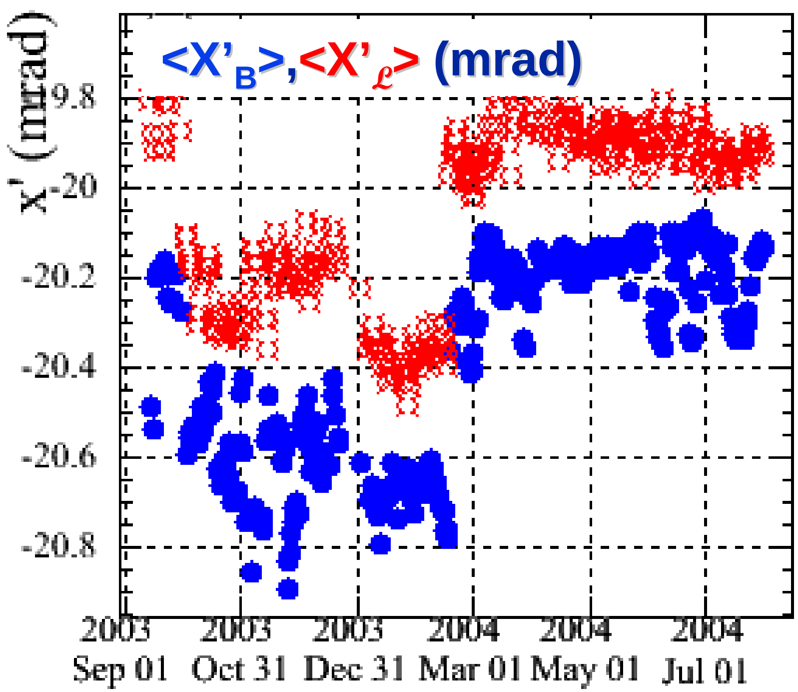
- <X'B>, <Y'B> is another measure of the collision axis

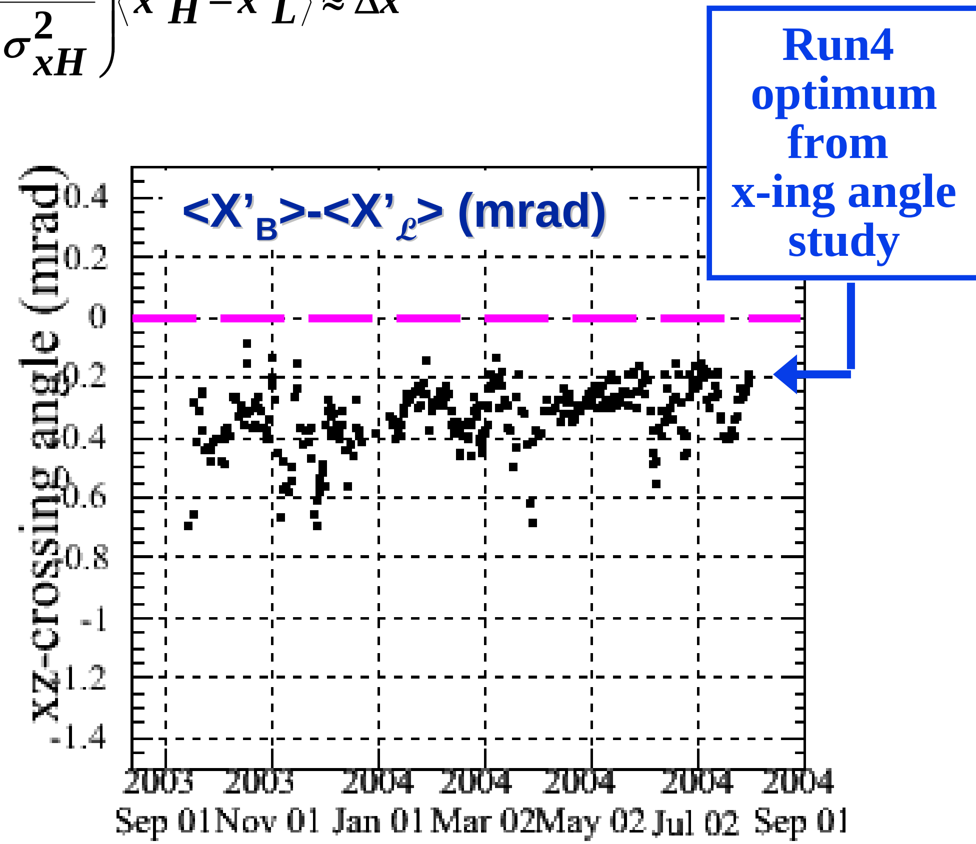




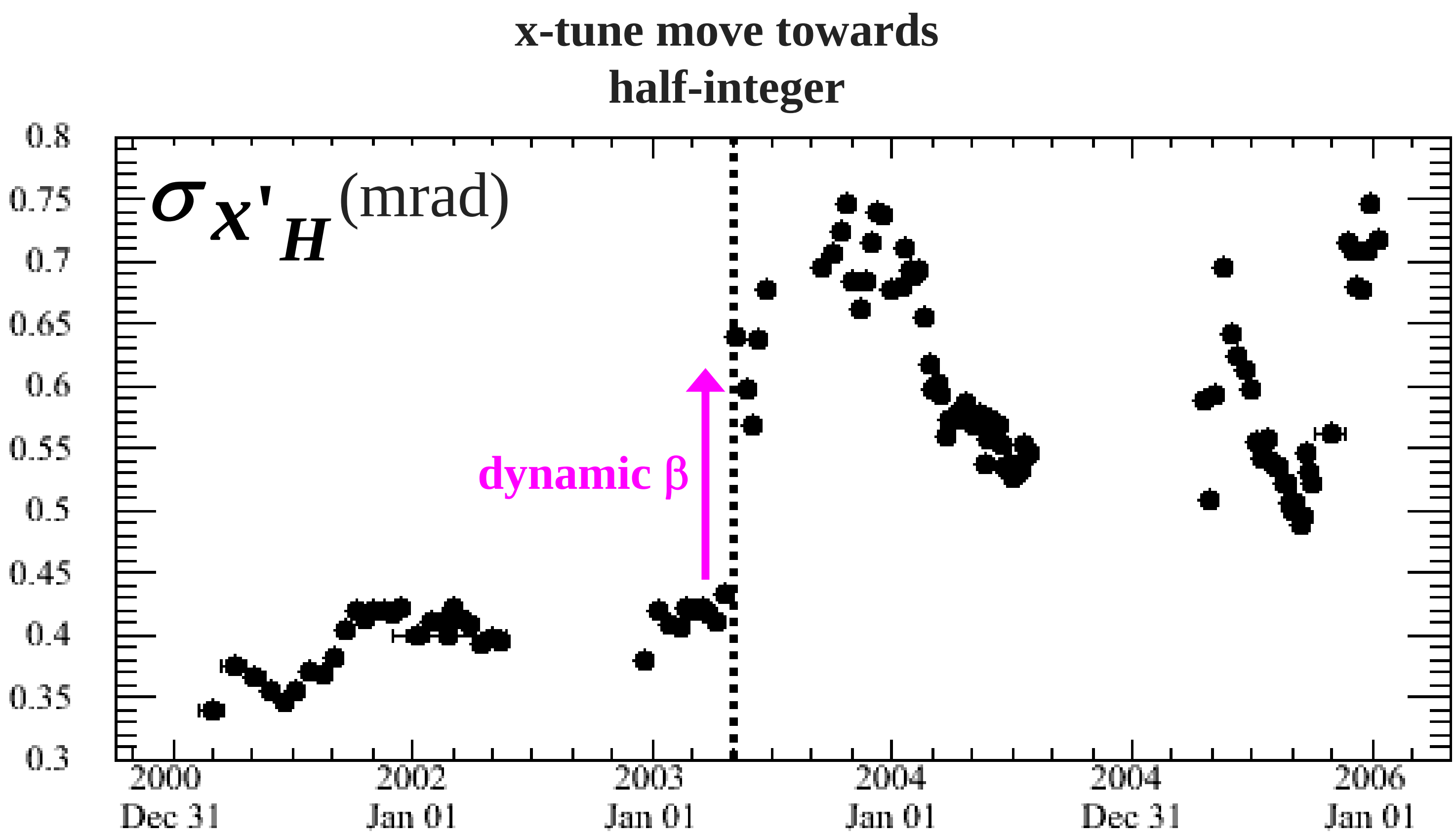
Crossing Angle

- $\langle X'_B \rangle - \langle X'_{\mathcal{L}} \rangle = \frac{1}{2}\left(\frac{E_H + E_L}{E_H - E_L} + \frac{\sigma^2_{xL} - \sigma^2_{xH}}{\sigma^2_{xL} + \sigma^2_{xH}}\right)\langle x'_H - x'_L \rangle \approx \Delta x'$





- $\sigma_{X'B}$, $\sigma_{Y'B}$ dominant contribution from electron beam

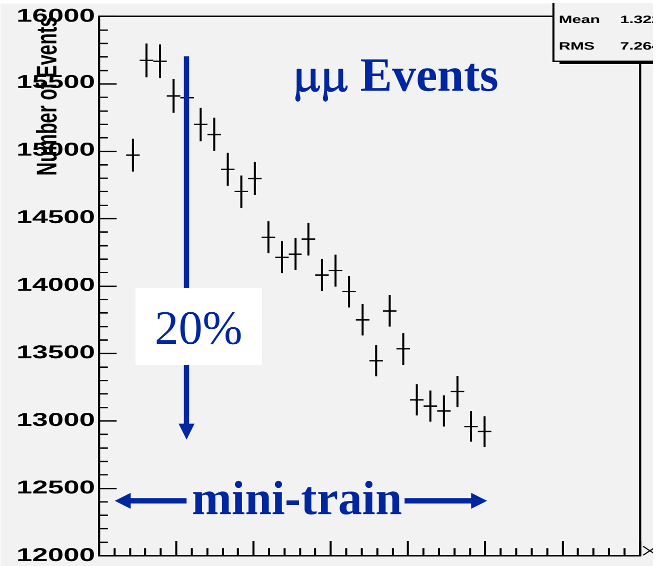


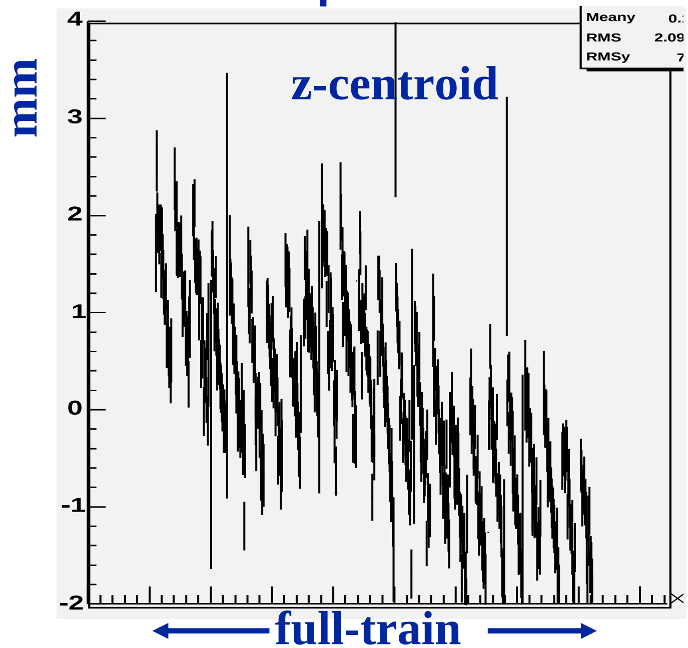
Studies on Luminosity Transient

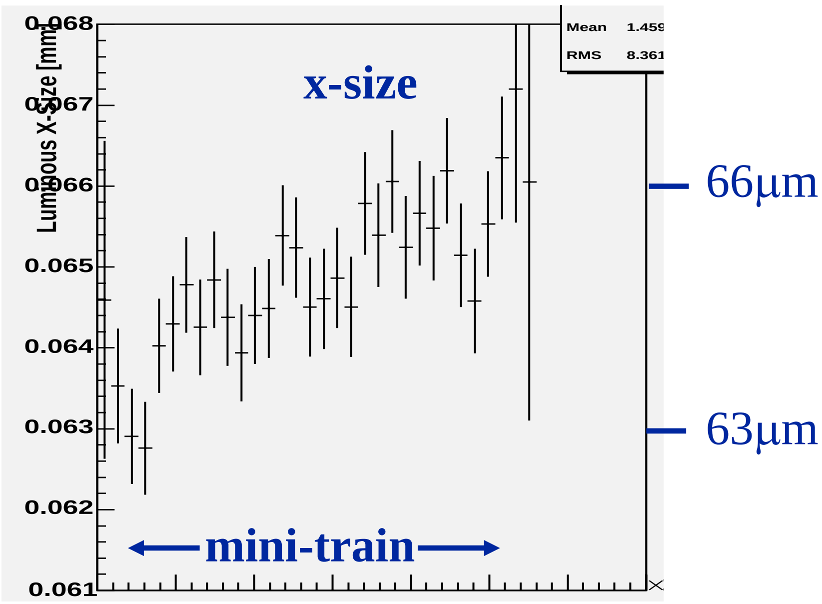
Track time resolution (~2ns) allows event association to RF bucket (476 MHz)

Studied many IP parameters along bunch train

- z-centroid, size
- x,y-centroids, x-size
- x',y' means and spread







β^*_y Msmts I - Luminosity (Z)

$$e^+e^- \to \mu^+\mu^-, e^+e^-(\gamma)$$

$$\mathcal{L}(z) = \frac{2N_1N_2}{\sqrt{(2\pi)^3}\,\Sigma_x\Sigma_y\Sigma_z} \times \exp\left(-2\frac{z^2}{\Sigma_z^2}\right)$$

$$\Sigma_y^2 = \left(\varepsilon_y\beta^*_{y\,HER} + \varepsilon_y\beta^*_{y\,LER}\right)\left(1 + z^2\frac{\varepsilon_y/\beta^*_{y\,HER} + \varepsilon_y/\beta^*_{y\,LER}}{\varepsilon_y\beta^*_{y\,HER} + \varepsilon_y\beta^*_{y\,LER}}\right)$$

$$\Sigma_z^2 = \sigma^2_{z,HER} + \sigma^2_{z,LER}$$

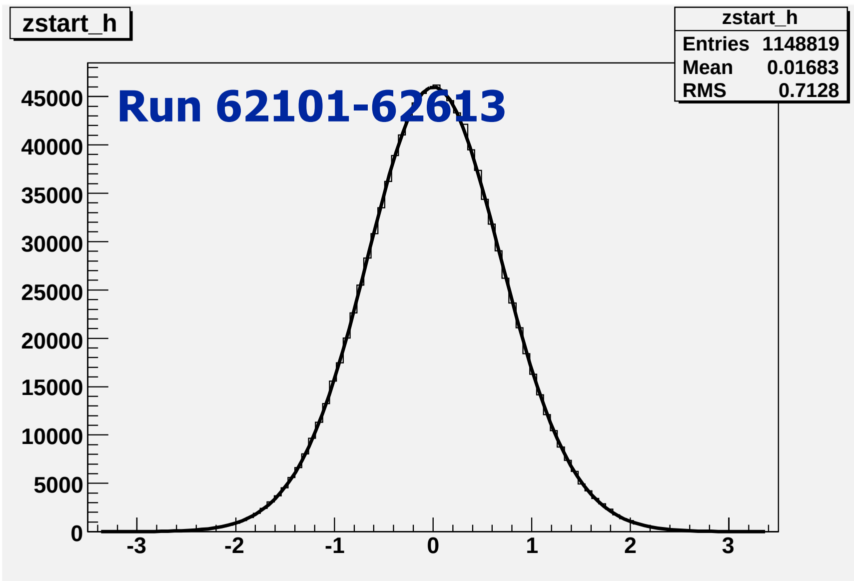
$$\frac{1}{\beta^{*2}_{y_{eff}}}$$

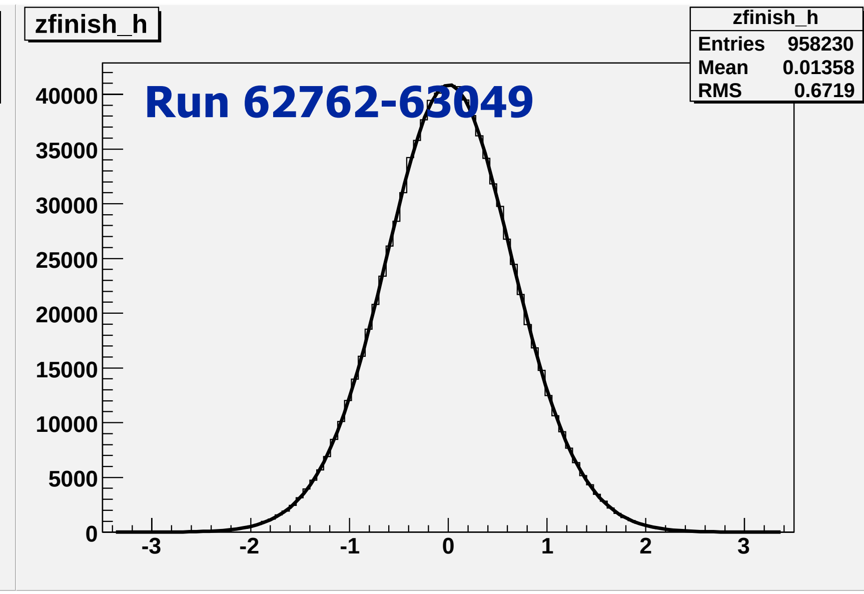
Z-resolution (~ 30μm) negligible compared to Σ_z, β^*_y

Only acceptance/efficiency matter

Neglecting complications from x-y coupling, dispersion,….

Luminosity (Z) Fits





Chisq: 108, for 100-5 d.o.f. Prob: 17%

Norm	1.02125e+00	1.47665e-03
Zc	3.68052e-02	2.66972e-03
CapSigzSqrd	2.45044e+00	1.03738e-02
BetaY	1.33328e+00	1.96984e-02
Waist	-8.00839e-02	1.26765e-02

Chisq: 132, for 100-5 d.o.f. Prob: 0.7%

Norm	1.02514e+00	1.63293e-03
Zc	2.64888e-02	2.62672e-03
CapSigzSqrd	2.21443e+00	9.75603e-03
BetaY	1.18414e+00	1.71040e-02
Waist	-4.35208e-02	1.11199e-02

β^*_y Msmts II - Luminous Y-Size (Z)

$$e^+e^- \to \mu^+\mu^-$$

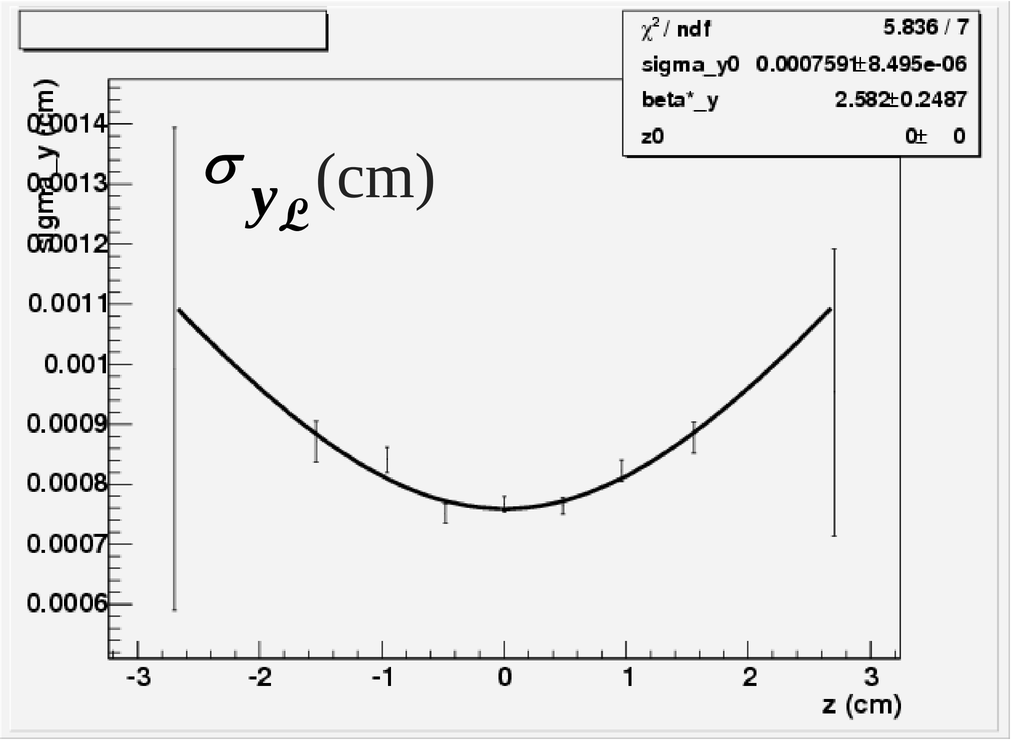
$$\sigma^2_{y_{\mathcal{L}}}(z) = \frac{\varepsilon_{y_H}\varepsilon_{y_L}}{\varepsilon_{y_H} + \varepsilon_{y_L}}\left(1 + \frac{z^2}{\beta^{*2}_y}\right)$$

Assumes common β_y^*

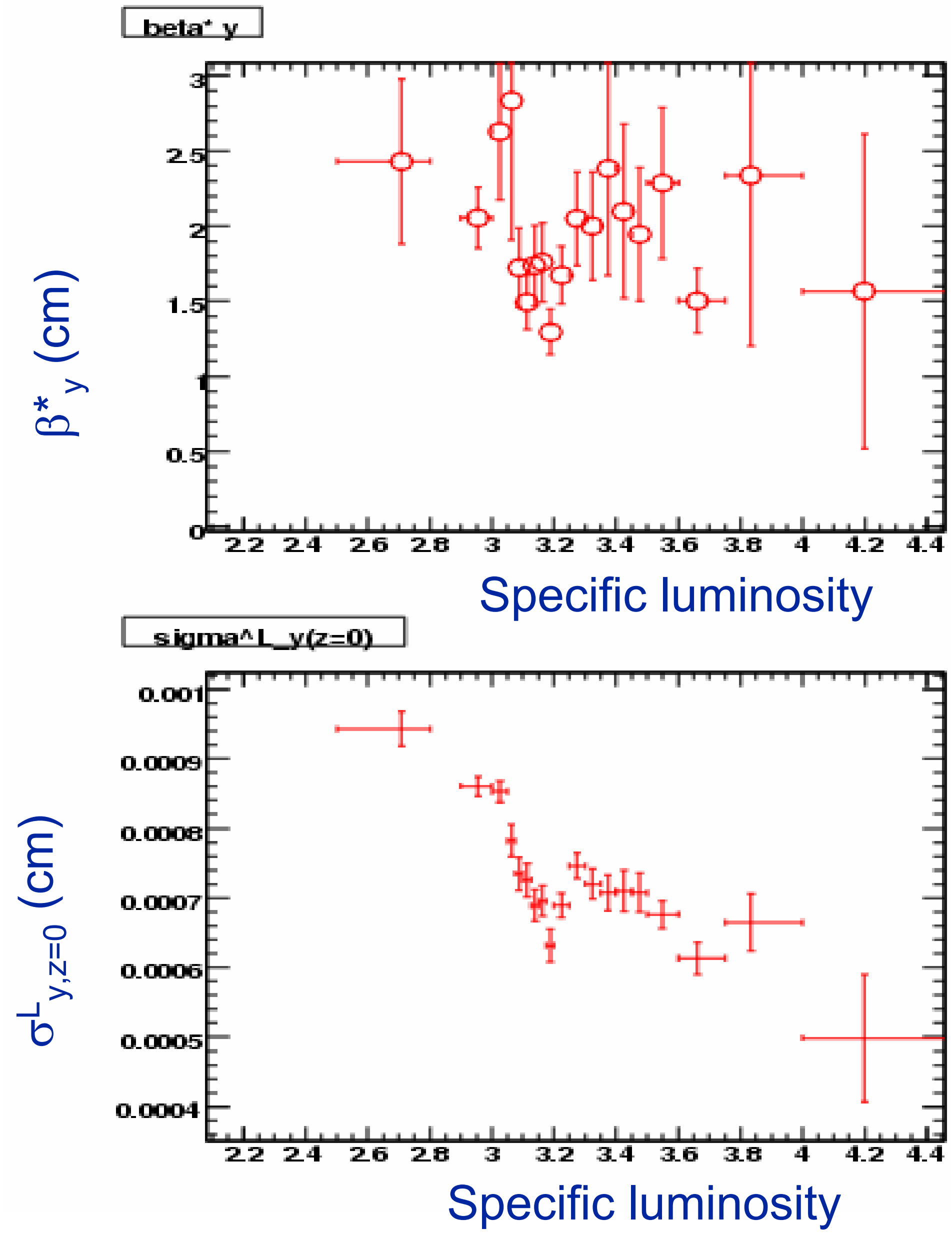
Y-resolution (30μm) large compared to $\sigma_{Y\mathcal{L}}$(~4μm).

Courageous analysis using track miss-distance to estimate per-event resolution.

Some systematics not resolved.

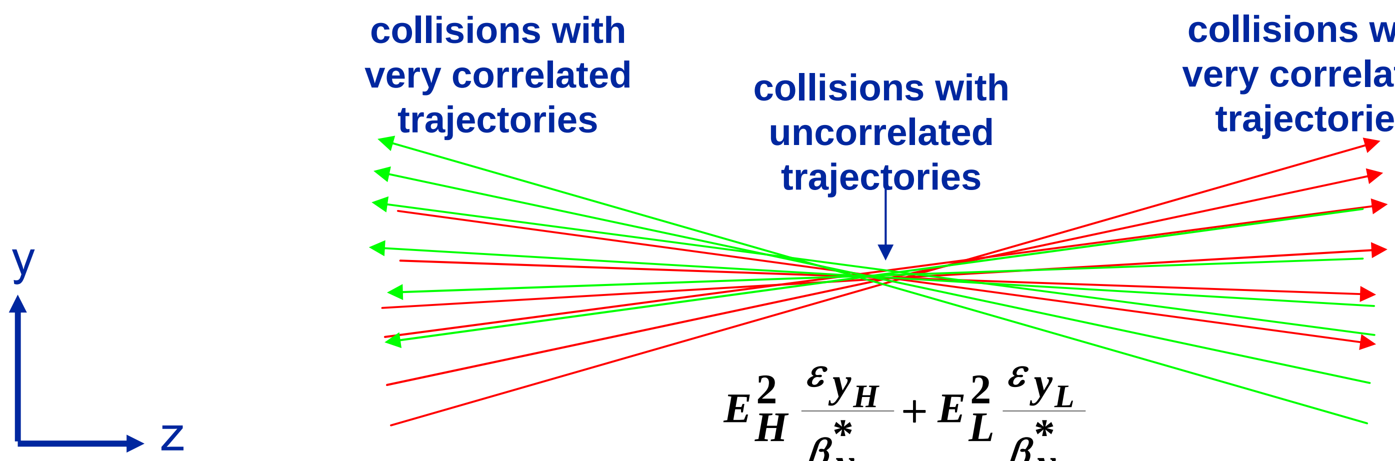


Luminous Y-Size (Z)



Nicely anti-correlated with Specific luminosity

β^*_y Msmts III - Boost Y-Angular Spread (Z)



$$\frac{\frac{\varepsilon_{y_H}}{\beta^*_{y_H}}+\frac{\varepsilon_{y_L}}{\beta^*_{y_L}}}{\frac{\varepsilon_{y_H}}{\beta^*_{y_H}}\,\frac{\varepsilon_{y_L}}{\beta^*_{y_L}}}$$

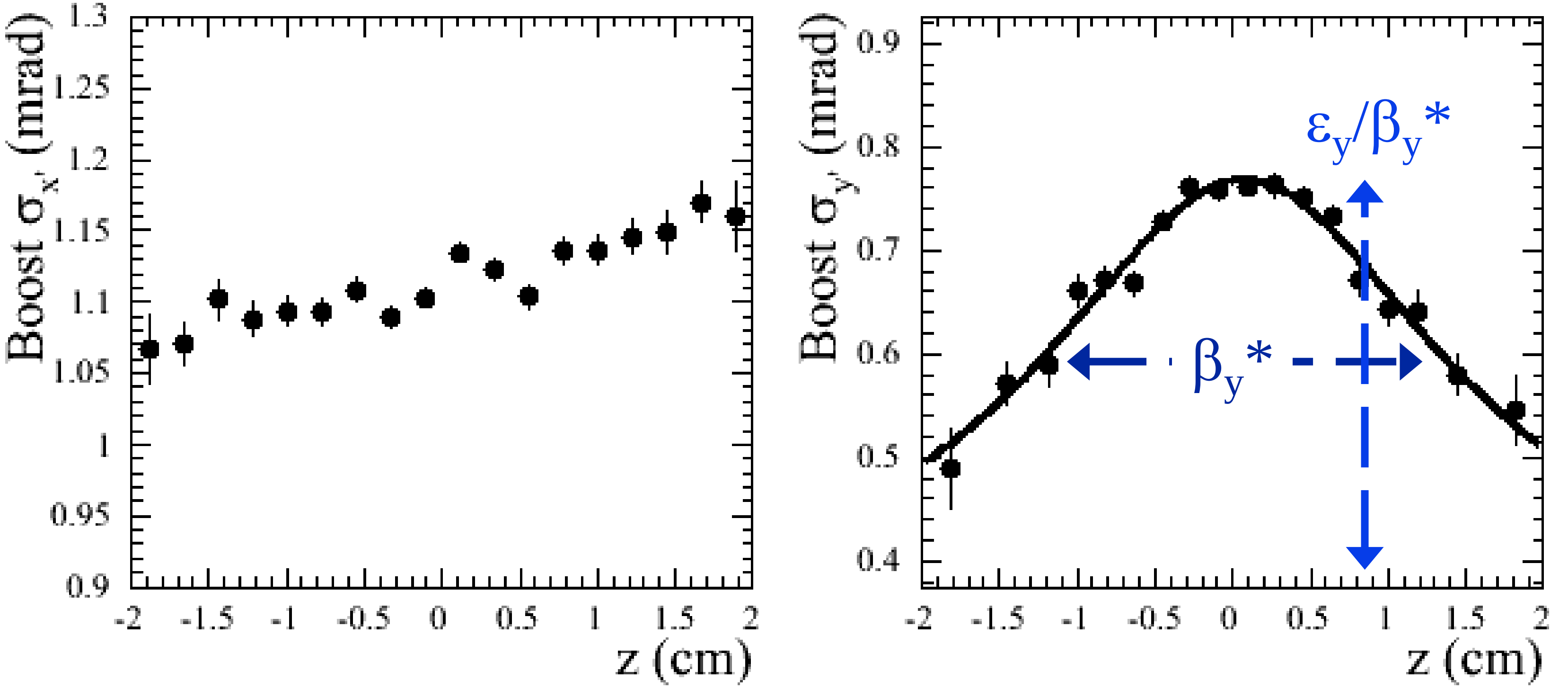
$$\frac{E_H^2\,\frac{\varepsilon_{y_H}}{\beta^*_{y_H}}+E_L^2\,\frac{\varepsilon_{y_L}}{\beta^*_{y_L}}}{(E_H - E_L)^2}$$

$$\sigma^2_{Y'B}(z) = \frac{(\varepsilon\beta_H+\varepsilon\beta_L)(f^2\varepsilon/\beta_H + f^2\varepsilon/\beta_L) + z^2\ \varepsilon/\beta_H\ \varepsilon/\beta_L}{\varepsilon\ \beta\ (1 + z^2 / \beta^2)_H + \varepsilon\ \beta\ (1 + z^2 / \beta^2)_L}$$

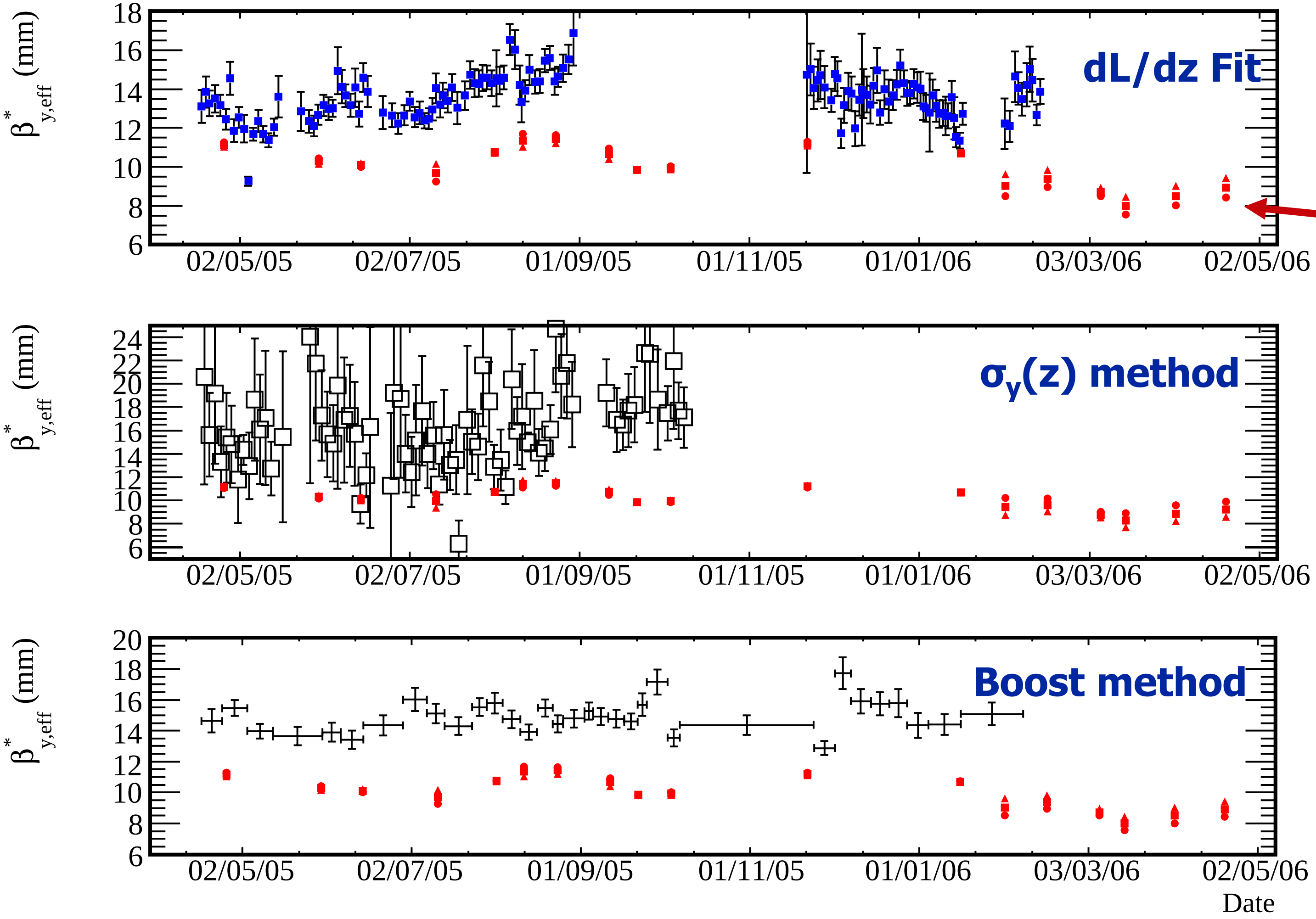
(all βs are at IP)

Depends upon vertical emittances and beta-stars

Boost Y-Angular Spread (Z)



β^*_y Msmts Compared



β_y^*(eff) from phase advance. Courtesy of Jerry Yocky.

β^*_y Msmts Compared

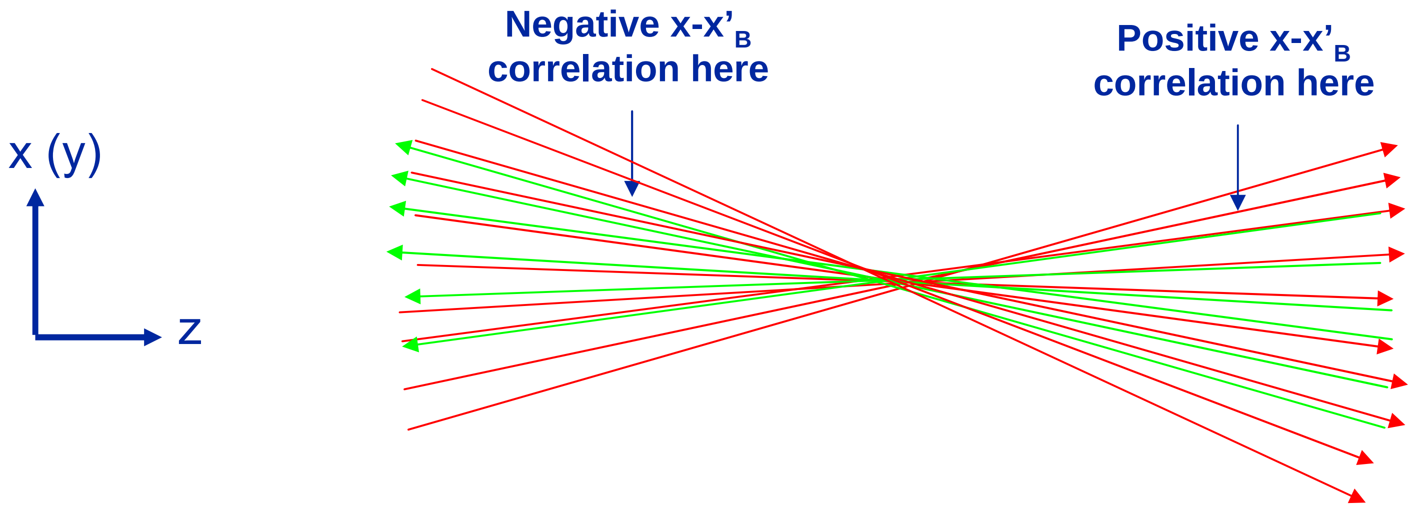
BaBar results are significantly higher than PEP measurements.

Possibilities:

- **Analysis errors**
- **Optics different low current vs in-collision**
- **X-Y coupling**

promising; under investigation

Boost Angle-Position Correlation

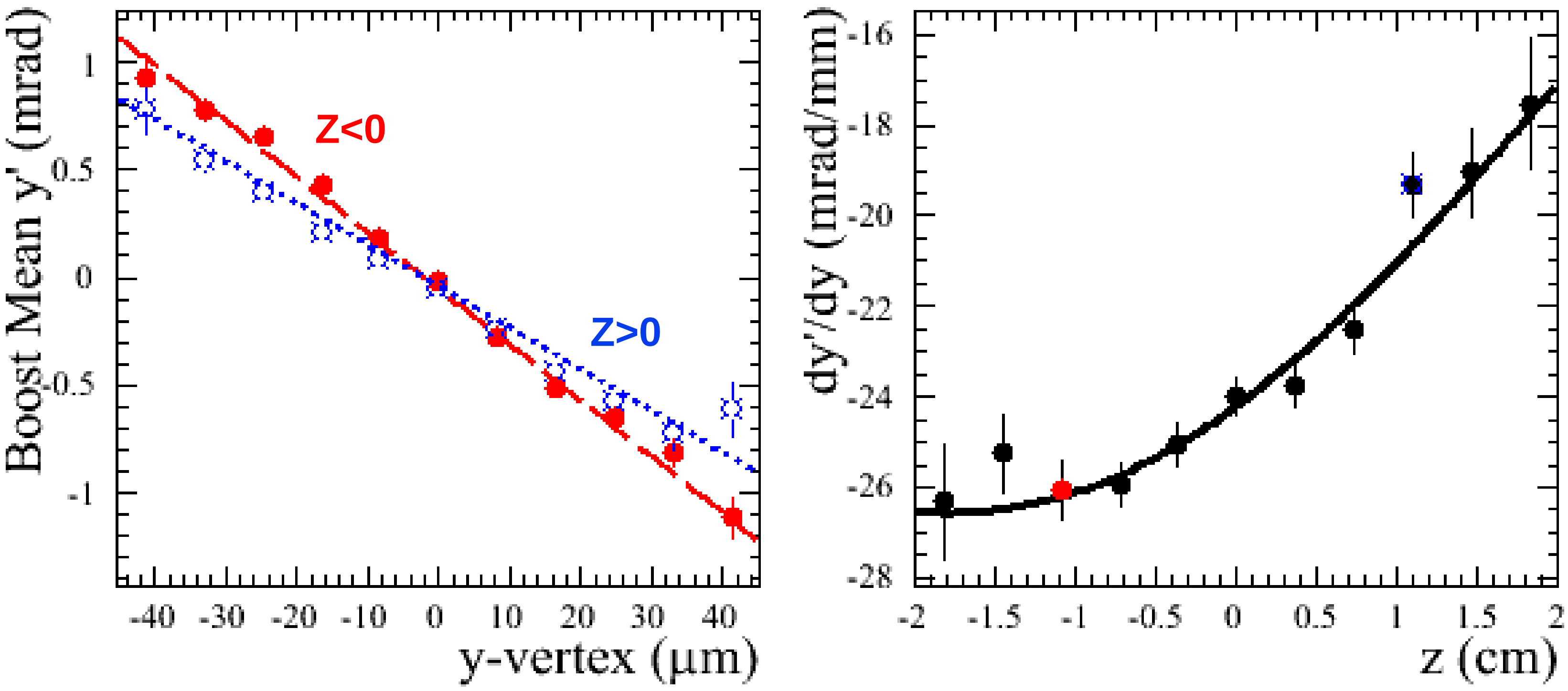


$$\overline{x'_B} = x \left(\frac{(z-z_H)\, f_H}{\beta^2_H+(z-z_H)^2} - \frac{(z-z_L)\, f_L}{\beta^2_L+(z-z_L)^2} \right)$$

(all βs are at IP)

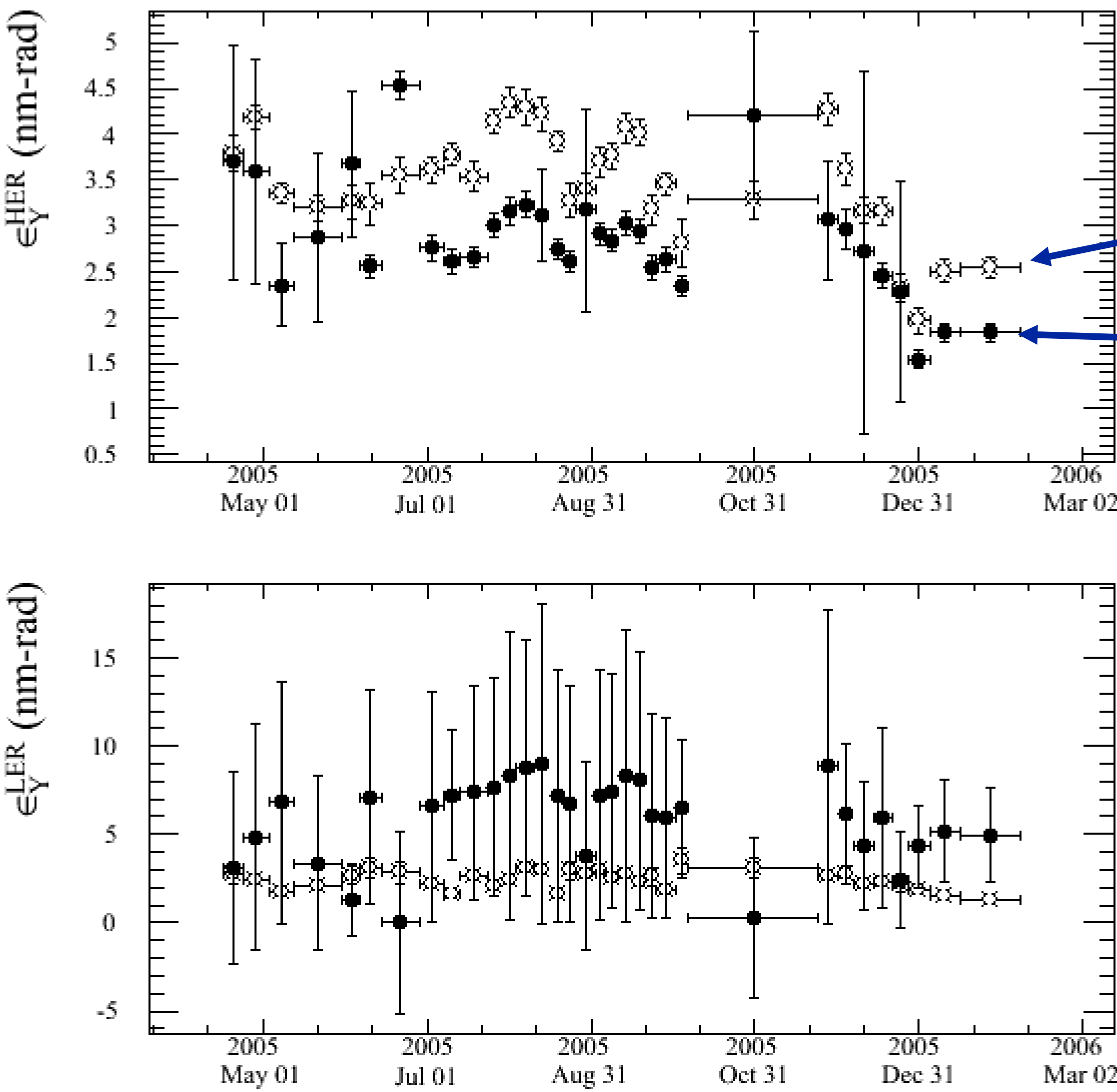
Depends upon beta-stars and waist locations

Boost Angle-Position Correlation



Adds an additional measured constraint upon vertical emittances and beta-function

Vertical Emittances



$\sigma_{y'}(z) + \sigma_{yy'}(z)$ fit

$\sigma_{y'}(z)$ fit only

Systematic shift not yet understood – coupling also possible explanation

IP Coupling Measurements

- X-Y Coupling may explain systematic effects in our measurements and (more importantly) degrade luminosity.
- Can we measure coupling parameters?
- Measurements to explore
  - X-Y Tilt of Luminous Region Ellipsoid
  - X'-Y' Tilt of Boost Vector Ellipse
  - X-Y' Boost Vector Position-Angle Correlation
  - Y-X' Boost Vector Position-Angle Correlation

BaBar IP measurements reported online

- **Luminous Region**
  - **centroids { x, y, z}** } **every 10 minutes**
  - **sizes { x, z }**
  - **tilts { dx/dz, dy/dz }**
  - **dL/dz fit { Σ_z, β^*_y }** — **every ~hour**

- **Boost Trajectory**
  - **mean { x', y' }** — **every 10 minutes**
  - **spread { x'_{HER}, y'_{HER} }** — **every 30 minutes**

IP Measurements at Super-B

- $\sigma_{y\mathcal{L}}$ will be much smaller (20 nm)
- $\sigma_{x\mathcal{L}}$ will be smaller than PEP-II $\sigma_{y\mathcal{L}}$
- Z-resolution still ~< "effective" bunch lengths and β_y^*
- Boost angular spread similar
- Boost angle-position correlation
  - larger intrinsic correlation ($1/\beta^2$)
  - smaller x,y coordinates
    x-may be possible, y-not
    may lose due to systematic effects (alignment)
- All online measurements still possible (except $\sigma_{x\mathcal{L}}$)
- Some offline analyses won't work; replace with new ideas
- Statistics will come much faster!

Summary

- BaBar is trying to contribute to the understanding of the PEP-II collider
- New ideas for measurements keep accumulating
- Understanding of IP parameter analyses seems to be converging.
- Hope that (this and) future experiment/accelerator combinations can benefit from our efforts

Spare Slides